

# PATTERN INSPECTION METHOD AND ITS APPARATUS

## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates to inspection for comparing an image of an object, which is obtained by using light, laser beams, or the like, and a reference image to detect a fine pattern defect, a foreign body, or the like from a difference between the images. In particular, the present invention relates to a pattern inspection apparatus preferable for performing visual inspection for a semiconductor wafer, a TFT, a photomask, and the like, and a method therefor.

### Description of the Related Art

As a conventional technique for comparing an inspection object image and a reference image to detect a defect, there is known a method described in JP-A-05-264467.

This method is for sequentially sensing images of an inspection object specimen with a line sensor, in which repetitive patterns are arranged regularly, comparing the sensed images with images delayed by time for a repetitive pattern pitch, and detecting a non-coincident part of the images as a pattern defect. Such a conventional inspection method will be described with visual inspection of a semiconductor wafer as an example. In the semiconductor wafer to be an object of inspection, as shown in Fig. 6, a large number of chips of

an identical pattern are arranged regularly. As shown in Fig. 7, each chip can be roughly divided into a memory mat section 71 and a peripheral circuit section 72. The memory mat section 71 is a set of small repetitive patterns (cells), and the peripheral circuit section 72 is basically a set of random patterns. In general, in the memory mat section 71, a pattern density is high and an image obtained by a bright-field illumination optical system tends to be dark. On the other hand, in the peripheral circuit section 72, a pattern density is low and an image to be obtained tends to be bright. In the conventional visual inspection, images in same positions of two chips adjacent to each other, for example, an area 61, an area 62, and the like in Fig. 6 are compared, and a difference between the images is detected as a defect. In this case, since there is vibration of a stage, inclination of an object, or the like and the positions of the two images do not always coincide with each other. Thus, an amount of positional deviation of the image sensed by the sensor and the image delayed by the repetitive pattern pitch is found, and the two images are aligned on the basis of the found amount of positional deviation, and then a difference between the images is calculated. When the difference is larger than a specified threshold value, it is judged that there is a defect in the pattern, and when the difference is smaller than the threshold value, it is judged that there is no defect in the pattern.

In the alignment of two images in the comparative inspection, it is a general practice to set edge parts in the images as one piece of information for calculation of an amount of positional deviation and calculate an amount of positional deviation such that deviation of the edge parts between the images is minimized. Actually, there have been proposed a method using normalized cross correlation, a method using a sum of residuals, and the like. However, in any of the methods, since an amount of calculation is enormous, in order to realize speedup of the inspection, measures such as changing a positional deviation amount calculation section to hardware or increasing arithmetic operation circuits, and change of an image processing algorithm such as simplification of the calculation of an amount of positional deviation have been required.

In addition, in the semiconductor wafer to be an object of inspection, a slight difference of thickness occurs in a pattern due to planarization of a CMP or the like, and there is a difference of brightness locally in images among chips. For example, reference numeral 41 in Fig. 4A denotes an example of an inspection object image, and reference numeral 42 in Fig. 4B denotes an example of a reference image. As indicated by 4a in Fig. 4A and 4b in Fig. 4B, a difference of brightness occurs in an identical pattern of the inspection object image and the reference image. In addition, there is a defect 4d in the inspection object image 41 of Fig. 4A. A difference

image in this case is as shown in Fig. 4C. A difference image means an image represented by a density difference according to a differential value in corresponding positions of an inspection object image and a reference image. A waveform of a differential value in position 1D-1D' is as shown in Fig. 4D. With respect to such an image, if a part where a differential value is equal to or more than a specific threshold value TH is regarded as a defect as in the conventional system, a differential value 4c of the patterns 4a and 4b which are different in brightness is detected as a defect. This should not originally be detected as a defect. In other words, it is false defect or nuisance defect (hereinafter refers as a false defect). Conventionally, as one method for avoiding occurrence of false defect such as the differential value 4c of Fig. 4C, the threshold value TH is increased (from TH to TH2 in Fig. 4D). However, this leads to decrease in sensitivity, and the defect 4d with a differential value of the same or lower level cannot be detected.

In addition, a difference of brightness due to a difference of thickness may occur only among specific chips within a wafer in the arranged chips shown in Fig. 6 or may occur only in a specific pattern within a chip. However, if the threshold value TH is adjusted to these local areas, overall inspection sensitivity is extremely decreased.

## SUMMARY OF THE INVENTION

The present invention reduces, in a pattern inspection apparatus for comparing images of corresponding areas of two patterns, which are formed so as to be identical, to judge that a non-coincident part of the images is a defect, influence of unevenness in brightness of patterns caused by a difference of thickness or the like and realizes highly sensitive pattern inspection. In addition, the present invention realizes high-speed pattern inspection without requiring changing an image comparison algorithm. Consequently, the problems of the conventional inspection technique can be solved.

In other words, in the present invention, the pattern inspection apparatus for comparing images of corresponding areas of two patterns, which are formed so as to be identical, to judge that a non-coincident part of the images is a defect includes means for performing processing for detecting an image with images sensor, processing for comparing images, and processing for judging a defect at different times. As a specific example of the means, the pattern inspection apparatus includes means for performing the processing for comparing images in parallel in plural areas. Therefore, the pattern inspection apparatus includes plural units for performing the processing for comparing images and memories of the number equal to or less than the number of the units. In addition, the pattern inspection apparatus includes means for writing data in a memory

of the image sensor and reading out data from the memory at different times.

Further, the pattern inspection apparatus includes means for converting gradation of an image signal among compared images by different plural processing units. Consequently, even in the case in which an object of inspection is a semiconductor wafer, and a difference of brightness occurs in an identical pattern among images due to a difference of thickness in the wafer, fluctuation in a quantity of illumination light, and fluctuation in sensitivity for each pixel of the image sensor, unevenness in quantity of light accumulation time, a defect can be detected correctly.

These and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 is a block diagram showing a schematic structure of an inspection apparatus according to the present invention;

Fig. 2 is an image diagram showing an example of a flow of image data in parallel processing by two image comparison processing units;

Fig. 3 is an image diagram showing another example of

the flow of image data in the parallel processing by the two image comparison processing units;

Fig. 4A is a diagram showing an inspection object image at the time when there is unevenness in brightness among compared chips in an example of a conventional threshold value setting method;

Fig. 4B is a diagram showing a reference image in the conventional threshold value setting method;

Fig. 4C is a difference image in the conventional the threshold value setting method;

Fig. 4D is a waveform diagram of a differential value in position 1D-1D';

Fig. 5 is a plan view of a semiconductor wafer and shows an enlarged view of an example of an image comparison processing unit;

Fig. 6 is a plan view of a semiconductor wafer and shows an enlarged view of a chip;

Fig. 7 is a plan view showing an example of a structure of a chip;

Fig. 8 is a flow diagram showing a flow of processing for adjusting a difference of brightness which occurs in a belt shape;

Fig. 9 is a flow diagram showing a flow of processing in the image comparison processing unit;

Fig. 10A is a diagram illustrating processing for

adjusting a difference of brightness which occurs in a belt shape and shows an example of adjusting a brightness in a row direction;

Fig. 10B is a diagram illustrating processing for adjusting a difference of brightness which occurs in a belt shape and shows an example of adjusting a brightness in a column direction;

Fig. 10C is a diagram illustrating processing for adjusting a difference of brightness which occurs in a belt shape and shows an example of adjusting brightness in a row direction and a column direction;

Fig. 11A is a diagram showing an example of a result of processing of a brightness correction unit and shows a difference image after alignment;

Fig. 11B a diagram showing an example of a result of processing of the brightness correction unit and shows an image in which a difference of brightness is corrected at a high frequency (by a unit of linear or belt-like area);

Fig. 11C a diagram showing an example of a result of processing of brightness correction unit and shows an image in which a difference of brightness is corrected at a low frequency (by a unit of a wide area);

Fig. 11D is a diagram showing an example of a result of processing of the brightness correction unit and shows a luminance waveform diagram in 1D-1D' in Fig. 11A;



Fig. 11E is a diagram showing an example of a result of processing of the brightness correction unit and shows a luminance waveform diagram of Fig. 11C corresponding to 1D-1D' of Fig. 11A;

Fig. 12 shows an example of a proper threshold value according to coordinates in a wafer and coordinates in a chip in a plan view of a semiconductor wafer;

Fig. 13 is a flow diagram explaining a flow of processing for setting a threshold value for each of the coordinates in a wafer and the coordinates in a chip;

Fig. 14 is a plan view of a semiconductor wafer showing an example of inspection chip setting at the time of trial inspection;

Fig. 15 is a front view of a displayed screen showing an example of superimposed indication of design data of a chip and processing results;

Fig. 16A is a graph showing an example of setting a threshold value from characteristic amounts of a defect and false defect and shows a relation between a density difference value and a frequency of the defect and the false defect;

Fig. 16B is a graph showing an example of setting a threshold value from characteristic amounts of a defect and false defect and shows a relation between an area and a density difference value of the defect and the false defect;

Fig. 17 is a flow diagram showing a flow of processing

for adjusting a difference of brightness which occurs at random;

Fig. 18A is a diagram showing a reference image, a detected image, and a difference image for which a brightness by a unit of belt-like area is adjusted;

Fig. 18B is a graph showing a characteristic amount space which is formed by the reference image and the detected image;

Fig. 18C is a scatter diagram in a characteristic amount space with a brightness of the detected image plotted on the X axis and a brightness of the reference image plotted on the Y axis;

Figs. 18D and 18E are scatter diagrams in which the scatter diagram of Fig. 18C is divided for each characteristic amount;

Figs. 19A and 19B are diagrams showing an example of a segment dividing method for a characteristic space; and

Fig. 20 is a flow diagram showing a procedure of processing for calculating a divided threshold value for the segment division.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

An embodiment of the present invention will be hereinafter described in detail with reference to Figs. 1 to 20.

As an embodiment, a defect inspection method in an optical visual inspection apparatus targeting a semiconductor wafer will be illustrated. Fig. 1 shows an example of a structure of the apparatus. Reference numeral 11 denotes a specimen (an

object to be inspected such as a semiconductor wafer); 12, a stage on which the specimen 11 is placed and moved; and 13, a detection unit including a light source 101 which illuminates the specimen 11, an illumination optical system 102 which condenses light emitted from the light source 101, an object lens 103 which illuminates the specimen 11 with the illumination light condensed by the illumination optical system 102 and focuses an optical image obtained by reflection of the illumination light, an image sensor 104 which receives the focused optical image and converts the focused optical image into an image signal corresponding to a brightness; and an AD conversion unit 105 which converts an input signal from the image sensor 104 into a digital signal.

Here, a lamp is used as the light source 101 in the example shown in Fig. 1. However, a laser may be used. In addition, light emitted from the light source 101 may be light of a short wavelength or may be light of a wavelength in a wide band (white light). In the case in which the light of a short wavelength is used, in order to increase resolution of an image to be detected (to detect a fine defect), light of a wavelength in an ultraviolet region (ultraviolet light: UV light) may be used.

In addition, it becomes possible to detect a defect at relatively high speed and with high sensitivity by adopting a time delay integration image sensor (TDI image sensor), which is constituted by arranging plural one-dimensional image

sensors two-dimensionally, as the image sensor 104 to transfer a signal detected by each one-dimensional image sensor to the one-dimensional image sensor in the next stage in synchronization with movement of the stage 13 and add up the signals.

Reference numeral 14 is an image edition unit, which includes a pre-processing section 106, which applies image correction such as shading correction and dark level correction to a digital signal of an image detected in the detection unit 13, and an image memory 107 in which digital signals of a detected image to be an object of comparison and a reference image are stored.

Reference numeral 15 denotes an image comparison processing unit which calculates defect candidates in a wafer used as a specimen. The apparatus includes plural image comparison processing units (15-1, 15-2). The image comparison processing unit 15-1 compares two images (a detected image and a reference image) stored in an image memory 107-1 of the image edition unit 14 and judges that a part where a differential value is larger than a threshold value is a defect. First, the image comparison processing unit 15-1 reads out digital signals of the detected image and the reference image stored in the image memory 107-1, calculates an amount of positional deviation for adjusting deviation of positions in a positional deviation detection section 108-1, and calculates an amount

of signal correction for adjusting deviation of brightness between the detected image and the reference image in a brightness correction section 109-1. Then, the image comparison processing unit 15-1 compares corresponding positions of the detected image and the reference image in brightness in an image comparison section 110-1 using the calculated amount of positional deviation and amount of signal correction, and outputs a part where a differential value is larger than a specific threshold value as a defect candidate. A threshold value setting section 111-1 sets a threshold value, which is used in extracting a defect candidate from a differential value, for each area and gives the threshold value to the image comparison section 110-1.

In the image comparison processing unit 15-2, processing is performed in the same procedure as the image comparison processing unit 15-1 using two images stored in an image memory 10-2.

Reference numeral 16 denotes an overall control unit including a user interface section 112 which has display means and input means for receiving the change of inspection parameters (a threshold value and the like used in image comparison) from a user and displaying information on a detected defect, a storage 13 which stores a characteristic amount of a detected defect candidate, an image, and the like, and a CPU (incorporated in the overall control unit 16) which performs various controls.

Reference numeral 114 denotes a mechanical controller which drives the stage 12 on the basis of a control command from the overall control unit 16. Note that the image comparison processing units 15-1 and 15-2, the detection unit 13, and the like are also driven according to a command from the overall control unit 16.

In the semiconductor wafer 11 to be an object of inspection, a large number of chips of an identical pattern are arranged regularly as shown in Fig. 6. In the inspection apparatus of Fig. 1, the semiconductor wafer 11 as a specimen is continuously moved by the stage 12 in the overall control unit 16, and in synchronization with this, images of the chips are sequentially captured from the detection unit 13, digital image signals of the same positions of adjacent two chips, for example, the area 61 and the area 62 in Fig. 6, are compared as a detected image and a reference image, respectively, according to the above-mentioned procedure, and a difference of the images is detected as a defect.

Here, the inspection apparatus of this example has the two image comparison processing units 15-1 and 15-2 and performs processing in parallel. In addition, the image memories 107-1 and 107-2 also correspond to the respective image comparison processing units. Fig. 2 is a diagram showing a flow of the processing. Here, a case in which seven chips, namely, chips 1 to 7, are inspected will be described.

First, the image sensor 104 sequentially captures images of the chips. In association with an image capturing speed of the sensor, the image edition unit 14 performs pre-processing of the chip images in the pre-processing section 106, and the chip images are written in the memory 107. In this case, the image of the chip 1 is written in the memory 107-1 for the image comparison processing unit 15-1, the image of the chip 7 is written in the memory 107-2 for the image comparison processing unit 15-2, and the images of the chips 2 to 6 are written in both the memories 107-1 and 107-2. On the other hand, the image comparison processing units 15-1 and 15-2 read out images from the memories 107-1 and 107-2, respectively, at speed which is half the writing speed, and when two images are read out, performs image comparison such as calculation of an amount of positional deviation, calculation of an amount of signal correction, and extraction of defect candidates in parallel with the reading-out of images. Processing speed of the image comparison also is half the image capturing speed of the sensor. The image comparison processing units 15-1 and 15-2 mutually perform inspection of the chips of the other unit in parallel.

Fig. 3 is a diagram showing a flow of another kind of processing. Here, in a time for capturing an image of one chip, the two image comparison processing units 15-1 and 15-2 perform image comparison of an area for a half chip, respectively, (e.g., with respect to a length  $L$  of the chip, the image comparison

processing unit 15-1 performs image comparison of a former half L/2 and the image comparison processing unit 15-2 performs image comparison of a latter half L/2). First, the image sensor 104 sequentially captures the images of the chips. In association with the image capturing speed of the sensor, the image edition unit 14 performs pre-processing of the chip images, and writes the image of the former half L/2 of each chip in the memory 107-1 for the image comparison processing unit 15-1 and writes the image of the latter half L/2 of each chip in the memory 107-2 for the image comparison processing unit 15-2. On the other hand, the image comparison processing units 15-1 and 15-2 read out images at speed which is half the writing speed, respectively, and when images for the two chips are read out, performs image comparison such as calculation of an amount of positional deviation, calculation of an amount of signal correction, and extraction of a defect candidate in parallel with the reading-out of the images. As shown in Fig. 3, the processing speed for the image comparison is also half the image capturing speed of the sensor. While an image for one chip is captured, the image comparison processing units 15-1 and 15-2 perform inspection for a half length of the chip, respectively, in parallel.

As described above, in the case in which the speed of the detection processing of an image and the speed of the comparison processing are different, in other words, inspection



speed corresponding to capturing speed of an image sensor can be realized by causing plural image comparison processing units to perform processing in parallel even if the processing speed of the image comparison processing unit 15 is half the image capturing speed for an object chip by the image sensor 104 and the image edition speed. For example, if the image capturing speed of the image sensor is 1.6 Gpps (pps: pixel per second) at the fastest when it is converted from a relation of an amount of acquired light or the like, even if a processing capability of the image comparison processing unit 15 is only 0.8 Gpps, which is half the image capturing speed, it becomes possible to realize the inspection processing speed of 1.6 Gpps by adopting this constitution. Naturally, even in the case in which the speed of the image sensor is higher, it is possible to cope with this speed by constituting the image comparison processing unit 15 described above with three or more image comparison processing units to cause them to process acquired image signals in parallel. In addition, it is also possible to cope with a case in which an image capturing range of the image sensor is increased.

In the above-mentioned embodiment, the case in which the image sensor 104 has a single output is described. However, even if the image sensor 104 is of a type provided with plural output terminals and outputs plural signals in parallel, signals can be processed in the same manner as the above-mentioned

embodiment to perform image processing at higher speed. In this case, plural signal lines are led out from the image sensor 104, and the plural signal lines are connected to plural A/D converters 105 corresponding thereto, respectively, and outputs from the plural A/D converters 105 are inputted to the image edition unit 14 and processed in the procedure as described above.

Next, the processing in the image comparison processing units 15-1 and 15-2 will be described in detail. First, the detected image signal and the reference image signal to be continuously inputted to the memory 107 are read out in synchronization with the movement of the stage. Since these image signals of two chips are not signals in completely the same position if the stage is vibrated or a wafer set on the stage is inclined, an amount of positional deviation between the two images is calculated in the positional deviation detection section 108. The calculation of the amount of positional deviation is sequentially performed with a specific length in a traveling direction of the stage as one processing unit. Reference numerals 51, 52, ... in Fig. 5 denote respective processing area in the case in which a length D (pixel) is treated as one processing unit. This unit processing area will be hereinafter described as a unit.

In this way, an amount of positional deviation is sequentially calculated by a unit of unit with respect to an

image to be inputted, for example, an amount of positional deviation is calculated in the unit 51 and a unit of an adjacent chip corresponding to the unit 51, and then an amount of positional deviation is calculated in the unit 52 and a unit of an adjacent chip corresponding to the unit 52. For the calculation of an amount of positional deviation, there are various methods using normalized cross correlation among images, a sum of density differences among images, a sum of squares of density differences among images, and the like. Any of the methods may be used. Further, alignment of two images is performed by a unit of unit on the basis of the calculated amount of positional deviation.

Here, in order to perform highly accurate alignment with respect to an amount of positional deviation calculated by a unit of unit, in the present invention, reliability of an amount of positional deviation calculated in each unit is evaluated (e.g., in the case in which an amount of positional deviation is calculated according to normalized cross correlation, a magnitude of a correlation coefficient). In a unit with low reliability (e.g., small correlation coefficient), an amount of positional deviation calculated in the unit is not used, and an amount of positional deviation is calculated from an amount of positional deviation calculated in a unit with higher reliability before or after (in terms of time) the unit by interpolation or extrapolation. Consequently, it becomes

possible to perform alignment following distortion of an image due to vibration of the stage even in the case in which there is only a little pattern information for calculation of an amount of positional deviation of the unit.

On the other hand, in the case in which plural output signal lines are connected to the plural A/D converters 105 from the image sensor 104, and outputs from the plural A/D converters 105 are inputted to the image processing unit 14, the calculation of an amount of positional deviation by a unit of unit is also performed in parallel and the alignment is also performed in parallel. A unit of an area which is divided in a direction perpendicular to a traveling direction of the stage and in which parallel processing is performed is hereinafter described as a channel. Here, in order to perform highly accurate alignment by a unit of channel as well following distortion such as vibration of the stage and fluctuation in a magnification of an optical system, it is also possible to extract an amount of positional deviation with high reliability (e.g., with a high correlation coefficient) from plural amounts of positional deviation calculated for each channel, subject the extracted plural pieces of positional deviation information to processing such as compilation and statistical processing to calculate an amount of positional deviation of a channel with low reliability.

As an example of the calculation, one amount of positional

deviation of a channel with highest reliability among all channels is found and is set as an amount of positional deviation of a channel with low reliability. Alternatively, plural pieces of positional deviation information with high reliability are subjected to processing such as compilation and statistical processing to uniquely calculate an amount of positional deviation common to all the channels to set the amount of positional deviation as an amount of positional deviation for each channel. Alternatively, it is also possible to interpolate an amount of positional deviation of a channel with low reliability from amounts of positional deviation of plural channels with high reliability by interpolation or extrapolation. The interpolation or extrapolation may be performed by linear interpolation, or distortion due to vibration or the like may be represented by curve approximation such as spline approximation. Consequently, it becomes possible to perform alignment following distortion of an image due to vibration of the stage or the like even in the case in which there is only a little pattern information for calculation of an amount of positional deviation of a channel.

Next, an amount of signal correction for adjusting deviation of brightness in the brightness correction section 109 is calculated for the aligned two images. As a cause of the deviation of brightness, there are factors such as (1) slight difference of a thickness among chips of a semiconductor wafer

as an object to be inspected, (2) difference of sensitivity of each pixel of an image sensor, (3) difference of an amount of accumulated light due to unevenness of speed of a stage, and (4) fluctuation in an amount of illumination light. Among the factors, whereas (1) occurs at random depending upon a pattern of the semiconductor wafer, (2), (3), and (4) occur linearly or in a belt shape on a detected image as characteristics inherent in the inspection apparatus.

Thus, in the present invention, first, a difference of brightness, which occurs in a belt shape as in (2), (3), and (4), is adjusted at a specific high frequency, and a difference of brightness, which occurs at random as in (1), is adjusted at a period different from the period (i.e., in a different processing area).

Fig. 8 shows a flow of processing for adjusting a difference of brightness which occurs linearly or in a belt shape. First, with respect to a detected image or a reference image for which alignment has been performed, an amount of correction for adjusting unevenness of brightness (unevenness of brightness by a unit of row), which occurs in a direction perpendicular to a traveling direction of a stage, is calculated (step 81 in Fig. 8).

An example of a method of calculating an amount of correction of brightness at a highest frequency, that is, for each row will be described below. First, as shown in Fig. 10A,

with respect to an object row (M pixels x one row), an amount of correction for adjusting a brightness is calculated using a value of N rows (M pixels x N rows) in the vicinity including the row. As an example of a method of calculating the amount of correction, a statistical amount is calculated as indicated by expression (1) below.

$$\begin{aligned}
 E_F &= \frac{1}{(N \times M)} \sum_N \sum_M F(i, j) \\
 E_G &= \frac{1}{(N \times M)} \sum_N \sum_M G(i, j) \quad \dots \text{expression (1)} \\
 \sigma_F &= \sqrt{\frac{1}{(N \times M)} \left\{ \sum_N \sum_M (F(i, j) - E_F)^2 \right\}} \\
 \sigma_G &= \sqrt{\frac{1}{(N \times M)} \left\{ \sum_N \sum_M (G(i, j) - E_G)^2 \right\}}
 \end{aligned}$$

Here,  $F(i, j)$  and  $G(i, j)$  indicate a brightness of a detected image and a reference image after alignment in a position  $(i, j)$ . Then, an amount of correction is calculated as indicated by expression (2) below.

$$\begin{aligned}
 \text{gain}_x &= \sigma_F / \sigma_G \\
 \text{offset}_x &= E_F - \text{gain}_x \cdot E_G \quad \dots \text{expression (2)}
 \end{aligned}$$

Correction of the object row is performed with respect to the reference image as indicated by expression (3) below.

$$G_x(i, j) = \text{gain}_x \cdot G(i, j) + \text{offset}_x \quad \dots \text{expression (3)}$$

Similarly, an amount of correction for adjusting

unevenness of brightness (unevenness of brightness by a unit of column), which occurs in parallel with the traveling direction of the stage, is calculated (step 82 in Fig. 8). First, as shown in Fig. 10B, an amount of correction for adjusting brightness is calculated with respect to an object column (one column x L pixels) using a value of N columns (N columns x L pixels) in the vicinity including the column, and correction of the object column is performed with respect to the reference image as indicated by expression (4) below.

$$G_y(i, j) = gain_y \cdot G(i, j) + offset_y \quad \cdot \cdot \cdot \text{ (数 4 )}$$

... expression (4)

Then, as shown in Fig. 10C a logical product is found to calculate an amount of correction of a brightness of each pixel which occurs linearly or in a belt shape (step 83 in Fig. 8).

If  $(F(i, j) - G_x(i, j)) < (F(i, j) - G_y(i, j))$       Amount of  
correction = gainx, offsetx

Else      Amount of correction = gainy, offsety

Next, an amount of correction for adjusting a difference of brightness, which occurs at random depending upon a pattern of a semiconductor wafer, is calculated at a frequency different from an amount of correction for the linear difference of brightness, that is, for each area of a different size.

As shown in a final difference image of Fig. 10C, a



belt-like difference of brightness (noise), which occurs vertically or horizontally in a traveling direction of a stage, is reduced by finding a logical product of respective pixels. However, the difference of brightness which occurs at random remains without being corrected. Consequently, in the present invention, adjustment of a brightness targeting the random noise, which remains in this way, is performed next. An example of a procedure therefor is shown in Figs. 17 and 18A to 18C.

First, as shown in Fig. 18A to 18C, with respect to a detected image and a reference image for which a belt-like brightness is adjusted, a characteristic amount of corresponding each pixel in a specific area is calculated to form a characteristic space of two-dimensional or more as shown in Fig. 18A (17-1). The characteristic amount may be any amount as long as it indicates a characteristic of each pixel such as a contrast, a brightness, a second deviation value, a density difference between corresponding pixels, or a variance value using a near-field pixel. Next, the characteristic space is divided into plural segments (17-2), and an amount of correction is calculated for each segment using a statistic amount of pixels belonging to the segment (17-3). This is equivalent to, with respect to each pixel in areas of the detected image and the reference image, resolve a scatter diagram 18B according to pixels in the areas, in which a brightness of the detected image is plotted on the X axis and a brightness of the reference image

is plotted on the Y axis, as shown in Figs. 18C and 18D, ... according to the characteristic amount, and calculate an amount of correction in each scatter diagram.

Figs. 19A and 19B shows an example of a division method for dividing the characteristic space of Fig. 18A into segments. In the present invention, the segment division is automatically performed according to an object image. An upper graph on Fig. 19A is an example of a characteristic space according to a brightness and a density difference, and a lower graph is a histogram showing frequency of each brightness (luminance value), which is an example of determining a division threshold value in a brightness direction from a histogram of brightnesses of an object image.

Fig. 20 is an example of a processing procedure therefor. First, a histogram of luminance values in an object area is calculated (20-1). This may be calculated from the detected image or the reference image, or may be calculated from an average value of two images. Next, the luminance histogram is smoothed to remove a small peak or the like (20-2), and a differential value of the smoothed histogram is calculated (20-3). Next, The differential value is checked from a side of lower brightness, and a luminance value at which the value changes to positive is set as Start and a luminance value at which the value changes to negative next is set as End (20-4). Then, a luminance value at which the differential value is maximized in a range from

Start to End is set as a threshold value for division (20-5).

Consequently, as shown in Fig. 19A, the division is performed in the part of the trough of the histogram. This indicates that the segment division is performed according to a pattern in the object area. It is possible to divide a luminance value according to the pattern in the image. It is also possible to divide a luminance value according to a fixed value set by a user as shown in Fig. 19B.

For the amount of correction of each scatter diagram resolved by the segment division, a linear equation is found by a least square approximation within the scatter diagram as shown in Figs. 18C and 18D, and an inclination and a y intercept are set as an amount of correction. In addition, an amount of correction may be found from pixels belonging to each segment as shown in the above-mentioned expression 1 and expression 2. Further, an area for forming a characteristic space can be set as an arbitrary area of pixels of  $1 \times 1$  or more. However, since a defect is also adjusted if correction is performed with a  $1 \times 1$  pixel of a highest frequency, the area is set so as to be slightly larger.

A result of the correction is shown in Figs. 11A to 11E. Fig. 11A is a difference image after alignment. A defect is in an encircled part. Fig. 11D shows a luminance waveform of two images after alignment of 1D-1D' including the defect part and a differential value at that point. A detected image has

a defect, and the defect part is brighter than the part around it. However, a reference image is generally bright, and a differential value of the defect part is smaller than the part around it. On the other hand, Fig. 11B is a difference image after correcting a difference of linear brightness at a high frequency. Belt-like unevenness of brightness is corrected. As a result, a luminance value is adjusted as shown in Fig. 11E, and the defect is made manifest. However, this depends upon a repetitive pattern, and a difference of brightness which occurs at random is not corrected.

Fig. 11C is a difference image after calculating an amount of correction from a statistic amount of an area (in this example, an entire area of the image of Fig. 11B), which is different from adjustment of a linear noise, and correcting a difference of brightness. In this way, amounts of correction are calculated in two or more different processing areas, whereby it becomes possible to correct differences of brightness, which occur in different circumstances, and make a defect of a feeble signal, which is embedded invisible in strong unevenness of brightness, manifest and detect the defect.

In the present invention, with respect to a remaining random noise, adjustment of a brightness can be further performed for each area with similar characteristics. For example, when a characteristic space is formed in both a bright area such as the peripheral circuit section 72 of Fig. 7, where false

defect easily occurs, and the memory mat section 71, and an amount of correction is calculated, it is likely that a defect in the memory mat section 71 is corrected. Thus, characteristic spaces are formed separately in the memory mat section 71 and the peripheral circuit section 72. In addition, some memory mat sections or some peripheral circuit sections are in an area where noise easily occurs, and other memory mat sections or other peripheral circuit sections are in an area where noise does not easily occur. In such a case, characteristic spaces are also formed separately. The areas can be divided on the basis of design information of chips such as CAD data, chip layout data, or chip images or can be divided on the basis of a result of a test inspection. In addition, an area forming one characteristic space may be discrete (discontinuous). A method of dividing an area may be described in detail later.

An effect of performing brightness correction of multiple stages with respect to an inspection image as described above will be described for the case of inspecting a pattern, which is formed on a semiconductor wafer covered by an insulating film with an optical transparent and flat surface through, for example, a CMP process. Images, which are obtained by sensing images of the wafer after the CMP processing in the detection unit 13, are affected by a distribution of an amount of reflected light or the like, which is caused by fluctuation in thickness of the insulating film in the wafer surface and irregularity

of a pattern in a chip, to be changed to images with a brightness fluctuated depending upon a place in the wafer. By performing the brightness correction in multiple stages at different frequencies with respect to the image with fluctuation of brightness according to the method described above, influence of the fluctuation of brightness among the images can be reduce to make a defect manifest. Thus, it becomes possible to improve a rate of detection of a defect.

In this way, after calculating an amount of correction for adjusting a difference of brightness by plural processing unit, comparison in brightness in corresponding positions of two images is performed in the image comparison section 110 using an amount of positional deviation and amounts of signal correction which are calculated at two different periods. Then, a part where a differential value is larger than the threshold value TH is detected as a defect.

To summarize the flow of this processing, as shown in Fig. 9, in the image comparison processing unit 15, first, an amount of positional deviation between a detected image and a reference image is calculated from an image signal, which is received from the image edition unit 14, in the positional deviation correction section 108 (1081), and positional deviation of the detected image and the reference image is corrected on the basis of this calculated amount of deviation (1082). Next, in the brightness correction section 109, an

amount of correction of brightness unevenness between corresponding linear and belt-like areas of the detected image and the reference image is calculated (1091), and then an amount of correction of random brightness unevenness between corresponding areas of the detected image and the reference image is calculated for each area larger than the linear and belt-like areas (1092).

Next, in the image comparison section 110, a differential image of the detected image and the reference image, which is corrected using information on the amount of positional deviation between the detected image and the reference image calculated in the positional deviation correction section 108, information on the brightness unevenness between the linear and belt-like areas calculated in the brightness correction section 109, and information on the amount of correction of random brightness unevenness calculated for each area larger than the linear and belt-like areas, is compared with the threshold value signal from the threshold value setting section 111 to detect a defect.

Here, in a semiconductor wafer to be an object of inspection, depending upon a position of a chip, there is an area which is not intentionally detected even if noise is large, false defect easily occurs, or there is a defect in the area because damage due to the noise, the false defect, or the defect is small. For example, in Fig. 7, the memory mat section 71 is

a set of small repetitive patterns (cells), and the peripheral circuit section 72 is basically a set of random patterns. In general, in the memory mat section 71, a pattern density is high and an image obtained by a bright-field illumination optical system tends to be dark. On the other hand, in the peripheral circuit section 72, a pattern density is low and an image to be obtained tends to be bright. Further, in an area in which an image signal to be inputted is large (bright area) such as the peripheral circuit section 72, since noise is large and false defect easily occurs, it is necessary to set the threshold value TH slightly larger. On the other hand, in the memory mat section 71, since an image signal to be obtained is small (the section is dark), it is necessary to set the threshold value TH smaller and perform inspection with high sensitivity.

In addition, in the case in which a difference of brightness occurs locally due to a difference of thickness in a specific pattern area between chips as shown in Figs. 4A and 4B, false defect easily occurs in this part. Thus, it is necessary to set the threshold value TH slightly larger. On the other hand, in the case in which the comparison is performed using an only threshold value TH for the entire area, it is inevitable to set a slightly larger threshold value which is suited to an area with large noise or an area where false defect easily occurs. Thus, sensitivity in the other areas falls. Therefore, as a method of performing inspection with high sensitivity over the



entire area, the present invention provides means for setting a threshold value according to an area.

12-1 in Fig. 12 indicates a threshold value for preventing false defect from occurring in a certain position in a chip and means that it is necessary to set different threshold values according to an area. Moreover, in a semiconductor wafer, a difference of brightness between chips tends to be larger in a part closer to the vicinity of a wafer. 12-2 in Fig. 12 indicates a threshold value for preventing false defect from occurring in a certain position in the wafer and means that it is necessary to set different threshold values according to a position of a chip. In order to realize highly sensitive inspection over the entire area of the inspection area in this way, in the threshold value setting section 111 of Figs. 1 and 9, a threshold value is set for each position of the chip in the wafer and each position in the chip. An example of a procedure for the setting is shown in Fig. 13.

First, a user sets general conditions (13-1) and performs trial inspection (13-2). In this case, if only a threshold value according to a pattern in a chip is set, an area for one chip is set as an inspection area (14-1 in Fig. 14). If a threshold value according to a position of a chip in a wafer is further set, chips on the entire surface of the wafer or at least from an end to an end of the wafer are set as an inspection area (14-2 in Fig. 14). Then, the user visually confirms

detected defect candidates and classifies them into real defects and false defect (13-3). For the confirmation, an image, which is sensed by image sensing means different from that at the time in actual inspection such as a high magnification camera, or an image used for the actual inspection may be used. In this case, it is also possible to perform auto defect classification (ADC) or the like in parallel with the inspection, and automatically classify defect candidates into defects and false defect using a result of the auto defect classification or the like without intervention of the user. Then, a result of classification is displayed together with the chip such that it is seen at a glance where in the chip the occurrence of false defect concentrates (13-4).

In the case in which plural chips are set as an inspection area, results of inspection in the respective chips are superimposed. Looking at the superimposed results, the user sets an area where the user wishes to decrease sensitivity, that is, an area where the threshold value is to be increased, and an area where the user wishes to increase sensitivity, that is, an area where the threshold value is to be decreased. In this case, as shown in Fig. 15, it is also possible to display the areas while being superimposed on design information of the chip such as CAD data, chip layout data, and a chip image. By the superimposition on the design information, it becomes easier to confirm whether the set areas are appropriate and

change the set areas. In addition, an area can be set automatically from the design information of the chip.

Next, a characteristic amount of an area for setting a threshold value for each set area is calculated (13-6). For example, the characteristic amount is a characteristic amount  $F(i,j)-G(i,j)$ , an area, or the like of an area where false defect occurs such as a density difference value (a difference of brightness between the detected image and the reference image) of false defect in an area where occurrence of false defect concentrates, a pattern density, brightness, or the like of an area where false defect occurs, and the like. In addition, in the case in which trial inspection is performed in plural chips, coordinates in a wafer of a chip where occurrence of false defect concentrates, a shape of occurrence of false defect in the entire wafer, and the like are also calculated. Then, a threshold value, which is not false defect, in each area is set from the characteristic amount in each area (13-7). For example, in the area where occurrence of false defect concentrates, detection of false defect can be avoided if the threshold value is set larger than the density difference value of false defect.

In addition, as described above, in an area where the pattern density is high or an area where background is dark, the threshold value is set slightly lower because false defect does not easily occur. On the other hand, in an area where

the pattern density is low or an area where background is bright, the threshold value is set slightly higher because false defect easily occurs. Further, the threshold value is set slightly higher in a chip which is away from a center of a chip or a wafer where false defect concentrates. Since information such as the pattern density and the brightness of background can be obtained from an image, division of an area is performed automatically.

As shown in Fig. 16A, the threshold value is basically set automatically from the density difference value of false defect, but may be set with reference to a threshold value set by the user in advance. In addition, as shown in Fig. 16B, a threshold value for judging detection or non-detection can also be calculated from the density difference value and the area. Naturally, it is also possible for the user to set the area and the threshold value for each area manually. Such automatic setting of the area and automatic threshold setting for each area are performed in 111 in Fig. 1, and only defect is detected in the image comparison section 110 using the threshold value.

Moreover, it is also possible to perform inspection with the threshold value determined in 13-7 in Fig. 13 and repeat 13-3 to 13-7 to perform tuning of parameters. In addition, in this case, 13-3 to 13-7 can also be repeated while changing optical conditions (a focal point, an amount of light, deflection

conditions, etc.) (13-8) to perform tuning of the optical conditions.

As described above, in the present invention, image comparison processing is performed in parallel in the inspection for comparing two images and detecting a defect from a differential value thereof, whereby an inspection speed equivalent to or close to an image capturing speed of an image sensor can be realized.

For example, if the image capturing speed of the image sensor is 1.6 Gpps (pps: pixel per second) at the fastest, even if a processing capability of the image comparison processing unit 15 is only 0.8 Gpps, which is half the image capturing speed, it becomes possible to realize the inspection processing speed of 1.6 Gpps by adopting the constitution in which two image comparison processing units are provided in parallel as in the present invention. Moreover, even in the case in which the speed of the image sensor is higher such as the case in which the image capturing speed of the image sensor becomes equal to or higher than 1.6 Gpps, the case in which an image accumulation time of the image sensor is reduced according to optical conditions, or the case in which a scan width to be scanned by the image sensor at one time is increased, it becomes possible to cope with the case without speeding up the image comparison processing itself by increasing the number of the image comparison processing units to N. For example, even in

the case in which the image capturing speed of the image sensor is further increased to 6.4 Gpps at the fastest, it is possible to cope with the case at the image processing speed of 6.4 Gpps by arranging eight image comparison processing units 15 with the processing capability of 0.8 Gpps in parallel.

In addition, by adjusting a difference of thickness among chips, a difference of sensitivity of each pixel of the image sensor, a difference of an amount of accumulated light due to unevenness of a stage speed, and a difference of brightness among the chips which occurs due to various factors such as fluctuation in illumination (unevenness of colors) at plural different frequencies (i.e., an amount of correction is calculated for each of plural different areas), it becomes possible to make a defect of a feeble signal, which is embedded in strong brightness unevenness, manifest and detect the defect.

Further, by dividing an inspection area into plural areas according to coordinates in a wafer and coordinates in a chip to automatically set a threshold value for each divided area, inspection sensitivity in each area can be optimized to realize highly sensitive inspection as a whole. In this case, by displaying design information of the chip such as CAD data and a chip image of the chip so as to be superimposed on a state of occurrence of false defect or a result of automatic area setting, confirmation and correction of a set area are facilitated. It is also possible for the user to set the

threshold value manually.

The processing of the image comparison processing units 15-1 and 15-2 according to the present invention described above is realized by software processing by the CPU. However, it is also possible to change a core arithmetic operation part such as normalized cross correlation operation and the formation of a characteristic space to hardware processing by an LSI. Consequently, further speed-up can be realized. In addition, even if there is a large difference of brightness among compared dies due to a slight difference of a thickness of a pattern after smoothing process such as a CMP or reduction of a wavelength of illumination light, it becomes possible to detect a defect of 20 nm to 90 nm according to the present invention.

Moreover, in inspection of a low k film, for example, an inorganic insulating film such as  $\text{SiO}_2$ ,  $\text{SiOF}$ , BSG,  $\text{SiOB}$ , or a porous silica film, or an organic insulating film such as methyl containing  $\text{SiO}_2$ , MSQ, a polyimide film, a parylene film, a Teflon (registered trademark) film, or an amorphous carbon film, even if there is local difference of brightness due to in-film fluctuation of a refractive index distribution, it becomes possible to detect a defect of 20 nm to 90 nm according to the present invention.

An embodiment of the present invention has been described with a comparative inspection image in an optical visual inspection apparatus targeting a semiconductor wafer as an

example. However, the present invention is also applicable to a comparative image in electron beam type pattern inspection. In addition, an object of inspection is not limited to a semiconductor wafer, and the present invention is applicable to a TFT substrate, a photomask, a printed board, or the like as long as a defect is detected by comparison of images.

As described above, according to the present invention, by performing image comparison processing in parallel, an inspection speed corresponding to a processing speed depending upon an image capturing speed of an image sensor, an image accumulation time, a scanning width, and the like can be realized.

In addition, by adjusting at plural different frequencies a difference of brightness among images to be compared caused by a difference of thickness among chips, a difference of sensitivity of each pixel of the image sensor, a difference of an amount of accumulated light due to unevenness of a stage speed, a difference of brightness among the chips which occurs due to various factors such as fluctuation in illumination (unevenness of colors), or the like, it becomes possible to make a defect of a feeble signal, which is embedded in strong brightness unevenness, manifest and detect the defect.

Further, since a threshold value can be set according to coordinates in a wafer and coordinates in a chip, it becomes possible to automatically optimize inspection sensitivity in



various places, and highly sensitive inspection can be realized. In this case, by displaying design information of the chip and a threshold setting area so as to superimpose one on top of another, adjustment of sensitivity such as confirmation and correction of the threshold value setting area is facilitated.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.